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The Role of Quantitative Uncertainty in The Safety Analysis of Flammable Gas Accidents in Hanford Waste Tanks

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Abstract

Following a 1990 investigation into flammable gas generation, retention, and release mechanisms within the Hanford Site high-level waste tanks, personnel concluded that the existing Authorization Basis documentation did not adequately evaluate flammable gas hazards. The U.S. Department of Energy-Headquarters subsequently declared the flammable gas hazard as an unresolved safety issue. Although work scope has been focused on resolution of the issue, it has yet to be resolved due to considerable uncertainty regarding essential technical parameters and associated risk.

Resolution of the Flammable Gas Safety Issue will include the identification of a set of controls for the Authorization Basis for the tanks which will require a safety analysis of flammable gas accidents. A traditional nuclear facility safety analysis is based primarily on the analysis of a set of bounding accidents to represent the risks of the possible accidents and hazardous conditions at a facility. While this approach may provide some indication of the bounding consequences of accidents for facilities, it does not provide a satisfactory basis for identification of facility risk or safety controls when there is considerable uncertainty associated with accident phenomena and/or data as is the case with potential flammable gas accidents at the Hanford Site. This is due to the difficulties in identifying the bounding case and reaching consensus among safety analysts, facility operations and engineering, and the regulator on the implications of the safety analysis results. In addition, the bounding cases are frequently based on simplifying assumptions that make the analysis results insensitive to variations among facilities or the impact of alternative safety control strategies. The existing safety analysis of flammable gas accidents for the Tank Waste Remediation System (TWRS) at the Hanford Site has these difficulties.

However, Hanford Site personnel are developing a refined safety analysis approach which will solve the two basic difficulties of defining the bounding case and assessing the impact of controls. The refined safety analysis does this by explicitly quantifying the effects of the uncertainty in the state of knowledge about accident phenomena and data and providing a consistent basis for calculating the impact of alternative control strategies on parameters that affect accident risk. The refined analysis allows the assessment of the risk impact of the variability in conditions (e.g.,

waste inventory) among storage tanks in the TWRS. Finally, the refined flammable gas accident safety analysis supports sensitivity studies to examine the impact on the results of differences in flammable gas accident perspectives.

The results produced by the refined safety analysis consist of scatter plots and ranges of frequencies and doses quantifying the risk of various flammable gas accident outcomes. This paper addresses how some of the challenges in the use of these results are being addressed to successfully use the refined safety analysis results as part of the authorization basis (AB) for TWRS. These include how the results are used with risk evaluation guidelines, in the decision process assessing various control strategies, and to support the AB review and approval process.

Introduction

High-level radioactive waste has been stored in large cylindrical underground tanks at the U.S. Department of Energy, Richland Operations Office (DOE-RL), Hanford Site in southeastern Washington State since 1944. Approximately 285 million liters of caustic waste are contained in 177 carbon-steel tanks. The waste forms in these single-shell tanks (SST) and double-shell tanks (DST) include liquids, slurries, salt cake, and sludges.

Radiolytic, thermolytic, and chemical reactions in the radioactive waste generate flammable gases, such as hydrogen and ammonia. These gas mixtures also include an oxidizer (nitrous oxide) and an inert component (nitrogen). Some wastes retain the gas mixture until a large amount builds up, and then a short-term gas release occurs into the tank headspace. Such a gas release can result in a flammable concentration in the tank headspace. The only remaining element required for a deflagration is an ignition source present at the time of the gas release.

Following a 1990 investigation into flammable gas generation, retention, and release mechanisms within the Hanford Site high-level waste tanks, personnel concluded that the existing Authorization Basis documentation did not adequately evaluate flammable gas hazards. The U.S. Department of Energy-Headquarters subsequently declared the flammable gas hazard as an unresolved safety issue. Although work scope has been focused on resolution of the issue, it has yet to be resolved due to considerable uncertainty regarding essential technical parameters and associated risk.

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Refined Safety Analysis

Hanford Site personnel are developing a refined safety analysis approach which will solve the two basic difficulties of defining the bounding case and assessing the impact of controls. The refined safety analysis does this by explicitly quantifying the effects of the uncertainty in the state of knowledge about accident phenomena and data and providing a consistent basis for calculating the impact of alternative control strategies on parameters that affect accident risk. The refined analysis allows the assessment of the risk impact of the variability in conditions (e.g., waste inventory) among storage tanks in the TWRS. Finally, the refined flammable gas accident safety analysis supports sensitivity studies to examine the impact on the results of differences in flammable gas accident perspectives.

The refined safety analysis strategy is based on methods for quantifying technical uncertainty that have been developed and successfully applied on other safety management processes within the U.S. Department of Energy (DOE)[1,2] and the U.S. Nuclear Regulatory Commission (NRC) [3,4]. In addition to using all available measured ("pedigreed") data and analysis results, this process also uses formal systematic expert elicitation on flammable gas technical parameters of highest uncertainty and consequence. The experts are not directly elicited on the risk of specific bounding accidents.

The focus of this refined process is to develop an Analysis Framework as a consistent method for quantifying the effect of potential controls on the risk of flammable gas accidents in the Hanford Site waste tanks. The Analysis Framework is a lumped parameter model of flammable gas accidents that computes; (1) accident frequencies and consequences; (2) the impact of controls on flammable gas risk; and (3) how the uncertainty in essential accident phenomena affects the computed risk. The risk evaluation method uses conventional accident analysis calculations to evaluate radiological dose consequences. The refined safety analyses are not traditional "bounding" safety assessments; they are "best estimates with quantified uncertainty." Only the method of quantifying essential parameter uncertainty distributions (i.e., determined by an expert elicitation process) differs from conventional safety analysis methods. Dose consequence results are expressed in terms of uncertainty distributions. Data, if or when they become available, can replace elicited parameter uncertainty distributions

The analysis framework is implemented in a software package referred to as the Analysis Tool (AT). The AT used to quantify risk and uncertainty of combustion accidents (for frequency and dose) for specific tanks and the change in risk that would result from using different flammable gas controls. Evaluating the risk for the tanks, then comparing the risk among different baseline conditions, allows the relative need for controls on individual or groups of tanks to be determined. This enables the optimal determination of controls to be used to manage the tank farms. By comparing the risk reduction and cost of each flammable gas accident control option, personnel can select the optimal controls after rating the cost/benefit performance of each control against the risk.

AT Computational Approach

For each trial, the AT analyzes the potential outcome of postulated Gas Release Events (GREs) in the tanks from three sources; 1) induced by operations; 2) seismically induced; and 3) spontaneous. Each GRE is analyzed to determine if it results in tank headspace concentrations exceeding the Lower Flammability Limit (LFL) of hydrogen in air. If it does, then it is considered a" hit", and further analyzed to determine its deflagration behavior. This includes determining the tank damage state caused by the burn, the amount of material released, and the consequence, frequency pair for the accident. If it does not exceed LFL, it is not analyzed further.

The user of the AT specifies the number of trials for each analytical case. The AT then selects values from the uncertainty distributions based on a Latin Hypercube sampling scheme and combines them with point values from the data base to compute the outcome of each trial. The AT quantifies the uncertainty associated with flammable gas accident risk by calculating the potential outcome of GREs a number of times as specified by the AT user. Each outcome has a risk (consequence, frequency pair) measure associated with it. The uncertainty is quantified by analyzing the results of all the risk measures.

Results

Unlike the traditional bounding safety analysis, the refined safety analysis produces a set of values for the risk of flammable gas accidents. These values include those cases where the AT predicts that GREs will not burn and therefore, result in "zero" risk and the hits (predicted burns). Figure 1 is an example of the results from an AT analysis. It only includes the hits, since the non-burns would all have zero dose. This figure plots the radiological dose, frequency pairs for hits for four tank damage states. The results can also be plotted by source and GRE efficiency. Toxicological consequence, frequency pairs are also available.

Example of Onsite Dose Consequence Results

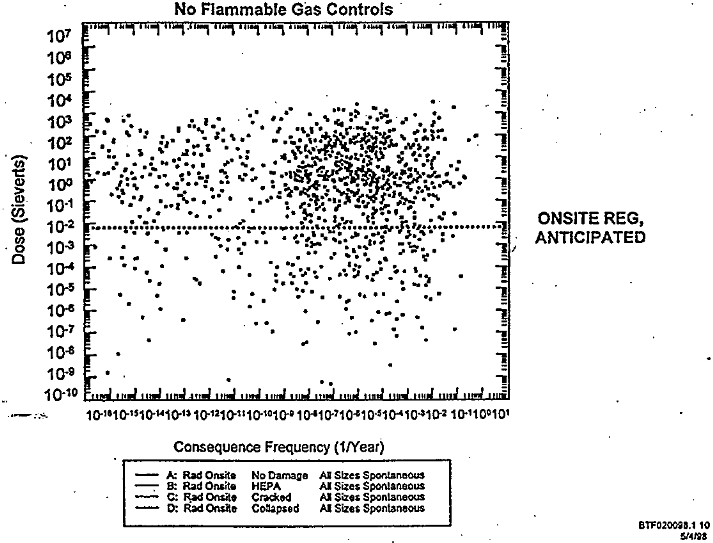

Figure 1. Scatter Plot Flammable Gas Accidents Hits.

The results that produce the scatter plots can be analyzed to produce uncertainty ranges as illustrated in Figure 2.

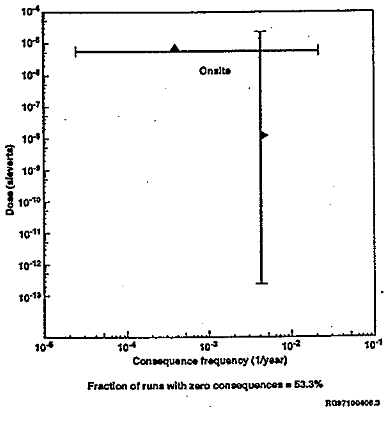

Figure 2. Uncertainty Range Cross Hair Plot.

The lines in Figure 2 plot the 90% uncertainty ranges for hit dose and frequency. The lines cross at the mean values and the triangles represent the median values. Both the scatter plots and cross hair plots can be developed for GRE sources, GRE sizes (efficiencies), and tank damage states. However, these plots only consider the hits. The AT run producing these illustrative results predicted 53% of the trials would not result in a deflagration.

To account for all the AT results, a measure referred to as expected risk is used. This measure includes all the consequence, frequency pairs, including the zero consequence ones. It is computed as follows:

$$R_{ex} = 1/N \sum_{1}^{N} (C_1 f_1)$$

Where:

R_{ex}	=	Expected risk
C	=	consequence
f	=	frequency
I	=	ith pair
N	=	total number of trials

Like the plots, expected risk can be developed for various GRE sources, sizes and tank damage states. Unlike the plots, the expected risk measure includes the results of all the trials.

Use of the Results

The results of the refined safety analysis are considerably more complex that the traditional safety analysis. The AT integrates many contributing factors to flammable gas risk in the computations as well as computing a range of potential outcomes. The challenge is to use these results to support the decision on selecting an adequate set of controls for potential flammable gas accidents at the Hanford high-level waste storage tanks. To accomplish this the results must be used in two ways:

1. Comparative Analysis, determining the relative impact on risk of various control strategies, including the "no controls" case.

2. Comparison to Risk Evaluation Guidelines, comparing the risk to risk evaluation guidelines for the purpose of control safety classification.

Comparative Analysis

The first way is relatively straight forward. The key is to select which risk measures to use in the comparison. The measures available are:

1. The number of hits: this gives a relative measure of the risk significance of the flammable gas accidents in a specific tank or group of similar tanks. For example, preliminary results indicate that in a thousand trials the number of hits varies from one (1) to twelve hundred (1,200).

2. Expected risk: this also provides a relative risk of tanks. Preliminary results indicate this measure can vary ten (10) or more orders of magnitude between tanks.

3. Statistical measures: these are derived from a statistical analysis of the hits and include the mean, median, 95% and 5% values of the consequence and frequency computed for the hits. Bar plots of these measures are useful when comparing the impacts of many different control strategies.

4. Uncertainty range: this provides an indication of the impact of the state of knowledge of flammable gas accident phenomena on the precision with which the risk is known. It also provides a context in which to judge the significance of the impact of a control strategy on risk.

The challenge with all these comparative risk measures is the shear number of them. They can be generated for various combinations of GRE sizes, sources and tank damage states. They can show large changes in relative risk for one combination, while overall risk is barely changed. Which of these measures are used in the final comparison to support the rationale for the selected control strategy has yet to be determined. However, it is clear that examining the multitude of measures available does provide insight into the magnitude of the impacts a particular control strategy is having and, to some extent, why. This is another benefit of having these various measures because it is important that the final comparison not only include the risk measure comparisons, but also provide rationale as to the physical impact of the controls on flammable gas accident phenomena.

Comparison to Risk Evaluation Guidelines

The Hanford Site uses a set of risk evaluation guidelines, primarily for the purpose of safety classification of controls. For radiological consequences ,these guidelines define dose levels for the offsite and onsite receptor for three frequency intervals. How to compare the AT results with the risk evaluation guidelines in use at the Hanford Site is not yet entirely resolved. This is, in part, because the guidelines were developed explicitly for the traditional single value bounding safety analysis results. In addition, they were developed to be applied on an individual accident basis.

Three concepts are presently being considered:

1. Identify the number, or percentage, of the AT GREs that have consequence, frequency pairs above guidelines: this would include consideration of all trial GREs - hits and non-hits. For this to be effectively implemented, all parties to the control decision process would have to agree on a criteria for determining when this comparison results in determining that the risk is above guidelines - when the percent above equals ?

2. Compare the mean values to guidelines: there is some regulatory precedent for this because the Environmental Protection Agency, in 40CFR191, Appendix B allows comparisons of means to risk guidelines for releases from high-level waste repositories. However, agreement would need to be reached on the inclusion all the non-hits.

3. Use the expected risk measure: Each frequency interval in the risk guidelines implies a number of expected risk values - for example the midpoint consequence, frequency pair, and the end points imply values. One of the difficulties is that the guidelines represent an infinite number of values, even including different values at the end points of adjoining frequency intervals. In addition, there is no agreement on what expected risk value(s) can be used for comparison purposes. However, at present, the expected risk is being used to indicate when expected risk value results are well below the implied values from the risk guidelines.

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